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A TECHNIQUE FOR THE PRECISE MEASUREMENT OF ACOUSTIC VELOCITY IN--ETC(U)
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SUBMITTED TO: GEOEXPLORATION

11 3 October 1978

12 5p.

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A TECHNIQUE FOR THE PRECISE MEASUREMENT OF ACOUSTIC VELOCITY IN, AND BETWEEN, BOREHOLES WITH A SPARKER SOURCE

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ABSTRACT

We describe a source, receiver, and measuring system for the determination of sound velocities in, or between, boreholes. A sparker source, dissipating 100-400J per shot, is used to generate acoustic pulses which are detected with barium titanate transducers at ranges to 80 m in the same or an adjacent borehole. The dominant frequency of the source is about 5 kHz and the precision of timing is better than 10μs. For measurement of mean P-wave velocity of about 50 m of crystalline rock between holes, an accuracy of ±0.02 km/s is possible with precise range measurement; the principal source of error is the uncertainty of hole-related delays. Use of larger source energies and multispark sources should permit ranges and, thus, accuracies a factor of 2 to 3 times better than those reported here to be obtained.

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INTRODUCTION

Knowledge of the seismic velocity structure of bedrock near surface is of value in a variety of ways in site investigation, because it contains information on weathering, extent of fracturing, and pore-fluid pressure as well as on the original petrological composition of the rock. Seismic refraction surveys at the ground surface usually lack resolving power because of the usage of low-frequency sources and because of the 'noise' generated by the variability of surface conditions. The conventional borehole technique (a continuous velocity log) is susceptible to significant error because of wall effects (caving, stress release in wall, pore-pressure alteration) over the short ray-paths involved and is constrained to measure velocity in the direction of the borehole only.

The capability of measuring travel-times of high-frequency (several kHz) acoustic energy over ranges to 100 m, both in and between boreholes, is potentially of value in overcoming the disadvantages of conventional techniques. We have designed, built, and used a system with such capability, based on an electrical sparker source. A similar device has been reported previously (McCann et al., 1975); our system has been proved to much greater depth (150 m), is capable of use in smaller diameter holes (2" diameter) and the downhole apparatus is particularly simple and inexpensive - both transmitter and receiver can be built in 24 hours from parts available from a plumbers' merchant, an electronics shop, and a bicycle outfitter. Travel-times of 10 ms in crystalline rocks have been measured with a precision

of 10μs. Moderate elaboration, principally a higher energy source and a little more filtering, would give greater range and correspondingly greater precision.

In succeeding sections, the apparatus is described and some results illustrate its use.

DESCRIPTION OF APPARATUS

The source

The electrical energy for the spark discharge is provided by a sparker driver (Edgerton and Hayward, 1964) consisting of 1-3 16μF capacitors charged to just over 4 kV: the stored energy delivered on triggering is thus 128-384J. All three capacitors were used for ranges of about 50 m, one was sufficient for work at about 20 m.

To connect the surface driver with the borehole probe we use ordinary laboratory co-axial cable RG58A/U. The cable is responsible for only modest energy loss. We use the snipped-off end of the co-axial cable core as the spark electrode.

Two downhole sparker probes were built, with outside diameters of 2.5 cm and 5.0 cm. The narrower probe consists of a perforated, 2.2 cm diameter, aluminium tube, length 15 cm, to which the stripped-back ground screen of the co-ax is soldered. The spark tip is held in the center of the tube by rubber spacers. This assembly is contained in a bicycle inner tube, filled with brine at a concentration of a few times that of a normal solution. The cycle tube is sealed with hose clamps. The wider probe is similar, except that the frame consists of four parallel 0.6 cm diameter threaded steel rods about 40 cm long held in place by four 5 cm diameter, 2.5 cm thick, PVC discs, through which holes are drilled for threading of steel rods along the edges and of the co-axial core along the center and for circulation of the brine. A larger inner tube surrounds the whole and is clamped as before.

In both probes the gap between spark tip and ground is about

1 cm. The tip wears away with usage at a rate of order 1 mm per 1000 shots: daily trimming is all that is required.

The receiver

In wide holes, we use a 7.6 cm diameter barium titanate disc (100 kHz resonant frequency) as a piezoelectric detector, mounted in a 10 cm diameter aluminium cylinder, and suspended on a steel-armoured logging cable. A pre-amplifier with battery pack is installed in the base of the cylinder to provide a variable voltage gain to a maximum of 100 (10 was used most often) and some filtering (generally a band of 500-7500 Hz was passed).

For work in narrow holes (down to 5 cm diameter) we use several 2.5 cm diameter 1 MHz barium titanate discs connected in parallel and cast in vertical line in epoxy into the top of which is cast a 15 cm length of 4 cm diameter iron pipe. The pipe contains a pre-amplifier identical to the one used in the wider receiver, and is sealed by a normal pipe end-cap through which a waterproof connector plug is mounted. The maximum diameter (on the end cap) is 4.5 cm.

In both receivers, we use disc-shaped piezoelectric detectors, polarized axially, mounted with the axis horizontal. Use of radially-polarized tubes might be more appropriate, but since the recorded events are at frequencies one to two orders of magnitude lower than resonance the transducers merely respond to the pressure change in the borehole water. The dominant wavelength, about 25 cm, is several times greater than the

width of the receiver probes, so that, at these frequencies the directional sensitivity of the transducers is low.

The measuring system

Figure 1 is a block diagram of the system. We measure travel time by using the delayed sweep of a Tektronix 556 dual-beam oscilloscope. Switching delays in the source are less than 1μs, the sweep delay is measured externally to the nearest μs or better. The P-wave arrival is photographed with a Polaroid camera fitting on the oscilloscope and the elapsed time on the sweep measured to the 1% sweep accuracy. Picking an event with onset 1 cm later than the beginning of a 0.5 ms/cm sweep gives an accuracy of ±5μs which is compatible with the accuracy of picking when the dominant period is about 200μs and the signal-to-noise ratio about 10dB. Figure 2 shows a photograph of an arrival detected in the Chelmsford (Mass.) granite, with source and receiver (narrow versions) at 58 m depth in separate holes 58 m apart. The top trace shows the received signal starting at the time of the shot instant at a scale of 2 ms/cm. The lower trace shows a portion of the top trace at a scale of 0.5 ms/cm and delayed by approximately 9 ms.

In cases where noise interferes with identification of onsets, repeat shots are used for clarification. In most such cases we find that picking gives times reproducible to better than 20μs, substantiating our claim of a general accuracy of time measurement of ±10μs.

The principal noise problem is 60 Hz pick-up even though

the level has been reduced by careful single-point grounding.

Modes of operation and results

The apparatus has been used in several ways to measure velocity variation.

In the Chelmsford granite we measured V_p horizontally as a function of depth between holes 58 m apart by lowering source and receiver to equal elevations in 10 m steps; we also measured V_p vertically by moving a source-receiver pair (separation 25 m) in 10 m steps down one hole. This work produced some striking comparisons between horizontal and vertical velocities and will be reported elsewhere in conjunction with laboratory measurements.

In a single hole in phyllite at Hollis, N.H., we measured V_p vertically using two techniques: one like that above - measuring the mean velocity between a fixed separation of the source-receiver pair; in the second technique the source was fixed at shallow depth and the change of travel-time to various receiver depths was used to calculate interval velocities. Comparison of the two velocity-depth profiles would provide a test of our claimed accuracy. Apart from fundamental timing accuracy, ±10μs, the main sources of error are uncertainties of range measurement (±5 cm at most) and wall delays (expected to lie in the range of 10-30μs). The error of measurement of velocity using the fixed separation (of 25 m) technique would then be +0.05, -0.01 km/s. The error of measurement using the interval velocity technique would be ±0.05 km/s. Figure 3 shows the results. Agreement of

the two sets of data is good, but range limitations and possibilities of signal shape change with range because of attenuation effects makes the interval velocity technique less useful. The estimates of wall delay (including water and stress-released rock effects) give adequate explanation of the small excess of interval velocities over mean velocities.

It is of interest to note that velocity increases rather rapidly in the top 50 m - a similar effect in the Chelmsford granite suggests closure of microcracks with load of overlying rock as the cause.

ACKNOWLEDGEMENTS

Dr. H.E. Edgerton provided the sparker driver. This development was undertaken while J. Hall was on study leave from the University of Glasgow, Scotland; their financial support is gratefully acknowledged. The work was carried out under Office of Naval Research Contract No. N00014-76-C-0478. New

NR-081-291

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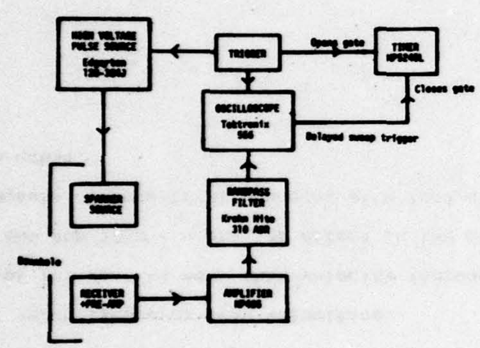

Figure 1. Block diagram of the velocity measuring system.

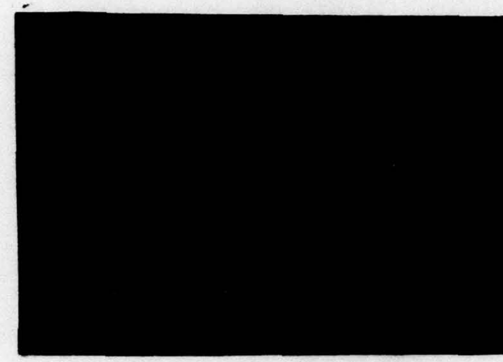

Figure 2. Oscilloscope display of arrival at 58 m range, source and receiver at 58 m depth. Upper trace time scale 2 ms/cm, lower trace time scale 0.5 ms/cm.

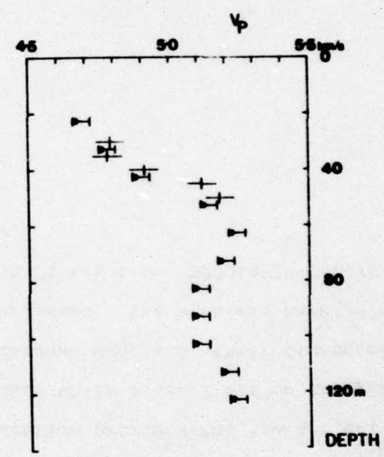

Figure 3. Plot of vertical V_p against depth as measured in a borehole in phyllite at Hollis, New Hampshire. A dot indicates a mean velocity, a plus indicates an interval velocity.